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Stabilized light intensity and small line width using UHF excitation

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With 14 figures in the text

SUMMARY

A UHF oscillator for 330–2400 Mc/s with triode RCA 6161 giving 120 W at 1000 Mc/s and used for excitation of discharge lamps is described. The input is regulated by a feedback loop composed of photomultiplier, amplifier, and power regulator. This gives precision stabilized light output. Wiring diagrams are shown. Several discharge tube types are examined regarding light density, and a simple one recommended. Spectral line widths are examined in a Hulthén immersion grating spectrograph with resolving power 10^6. Reproductions are given of the lines Hg 5461 and 4358, and Cd 4678.

Introduction

UHF and microwave excitation of gases and vapors is met with increasing interest. The advantages of a low temperature light source with high intensity are useful to many kinds of spectroscopic measurements. Much work has also been done on the design of special lamps suitable for this type of excitation, for instance at the National Bureau of Standards [1, 2], AF Cambridge Research Center [3], and the University of Southern California [4].

At the University of Stockholm great interest is given to high resolution spectroscopy and hyperfine structure investigations. This purpose demands for light sources with small line widths and sufficient intensity, which can be given by UHF excitation. A suitable oscillator with necessary instrumentation has therefore been built and experiments with different types of lamps have been made. The desired objects were high frequency, high power output, stabilized light intensity for scanning, and high light density in an area convenient for projecting on a slit.

The apparatus

The apparatus is separated in three parts, the oscillator, photomultiplier, and power units, which are interconnected by shielded cables. The oscillator unit is adjustably attached to a stand and contains the oscillator with output circuit including the discharge lamp. This makes the lamp easy to adjust in the optical path. The photomultiplier unit is small and can be fixed in any suitable position in relation to

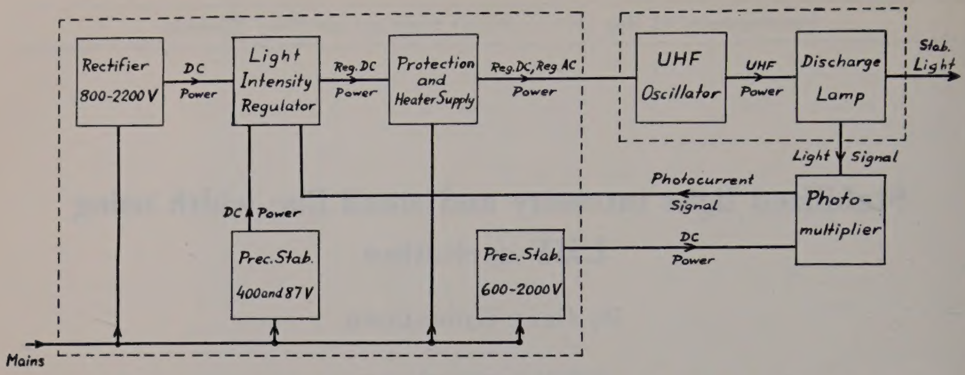

Fig. 1. Block diagram of the apparatus showing the light stabilizing feedback loop.

the discharge lamp and the spectrograph. The power unit is an electronics rack containing power supplies, controlling devices, and protecting relays. A block diagram of the apparatus is given in Fig. 1. The UHF Oscillator and the Discharge Lamp enter into the oscillator unit, while the Rectifier, the Light Intensity Regulator and Precision Stabilized 400 V, the Protection and Heater Supply, and the Precision Stabilized 600–2000 V form sub-units of the power unit.

The oscillator

The oscillator uses the triode RCA 6161 and gives frequencies between 330 and 2400 Mc/s (90–12.5 cm wavelength) with useful power output of about 120 W at 1000 Mc/s.

As there is some interest in varying the frequency of excitation, a triod oscillator with coaxial resonators has been chosen. The design follows mainly conventional lines as given in textbooks and papers on this subject, for instance [5] and [6].

The triode originally chosen for this purpose was the RCA 5588, which now has been superseded by 6161. The tube is specially designed to fit directly into coaxial resonators. The plate and cathode resonators are of this kind and placed in opposite directions from the tube, giving an oscillator type of common grid earthed grid. An outline of the arrangement is given in Fig. 2.

The tube is forced air cooled, the air being fed through the inner conductor of the plate resonator, through the radiator of the tube, and out through radial holes in the grid-connected wall, separating the plate and cathode resonators. There is proper protection against too low air flow by an air flow switch inside the inner plate conductor. If this switch opens by too low air flow, all voltages supplied to the tube are cut off by a relay. The cathode of the tube is protected by a relay, which cuts off the plate supply at too low heater current. The tube is also protected against overload by an adjustable relay, which cuts off the plate supply if the current exceeds the maximum rating.

The tube calls for a decrease of the heater power with increase of the tube DC currents when oscillating. This is because the heating of the cathode by electron back bombardment is considerable at these frequencies. It is inescapable that these currents show quick variations, within broad limits, due to tuning of the output circuit and changes in discharge intensity, seeing that the oscillator is used for experiments with

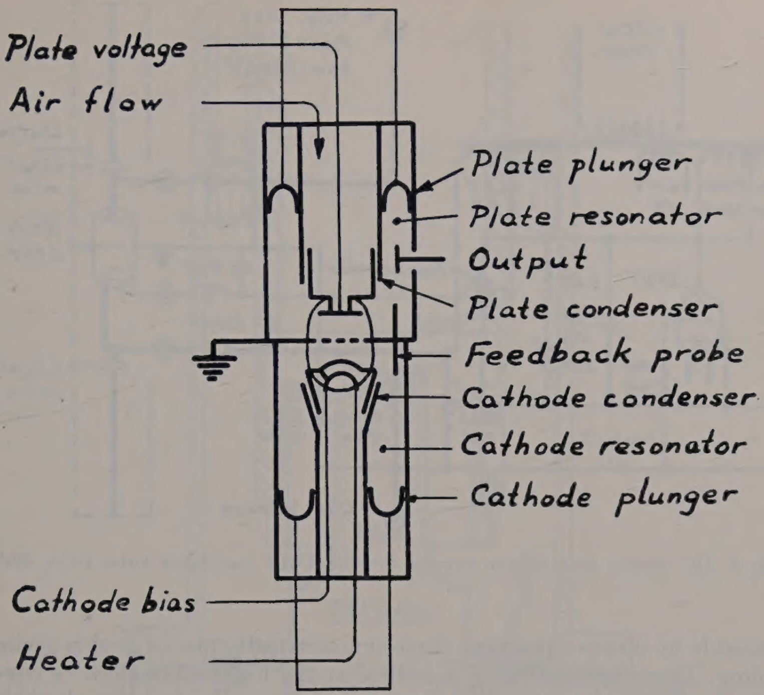

Fig. 2. Outline of the UHF oscillator.

the loading discharge lamps. The regulation of heater power with plate current is therefore arranged to be automatic, in order to simplify the operation of the oscillator system. The heater current is regulated by a cathode DC current controlled reactor (transductor), as shown by the diagram, Fig. 3. The proper rate of decrease in heater power versus plate current depends upon the frequency and is adjusted by the potentiometer 10 kΩ.

The DC bias circuit is shown in Fig. 3. An adjustable 250 Ω cathode resistor and a variable 2 kΩ 20 W grid resistor are used. The protection relays and the bias and heater circuits are included in the Protection and Heater Supply sub-unit. This also contains instruments for measuring plate voltage and current, grid current, and heater voltage. Plate and heater power and cathode bias are supplied to the oscillator triode through the inner conductors of the resonators.

The anode and cathode resonators are made from silverplated brass and the pushable short-circuiting plungers from hardened and silverplated beryllium-copper alloy. The inner conductors of the resonators are fitted with mica condensers near the high frequency current minimum at the tube connections. At the 440 pF plate condenser the 0.2 mm mica sheet is placed directly upon the plate connection ring, thus using the ring as one condenser plate. The end of the inner conductor tube is split open and clamped around the mica and the ring, serving as the other condenser plate and the triode holder. The 670 pF cathode condenser consists of two 0.04 mm mica sheets between conical condenser plates. The cathode and grid contacts are sleeve-type fingers made from 0.3 mm beryllium-copper. The plate-cathode feed-

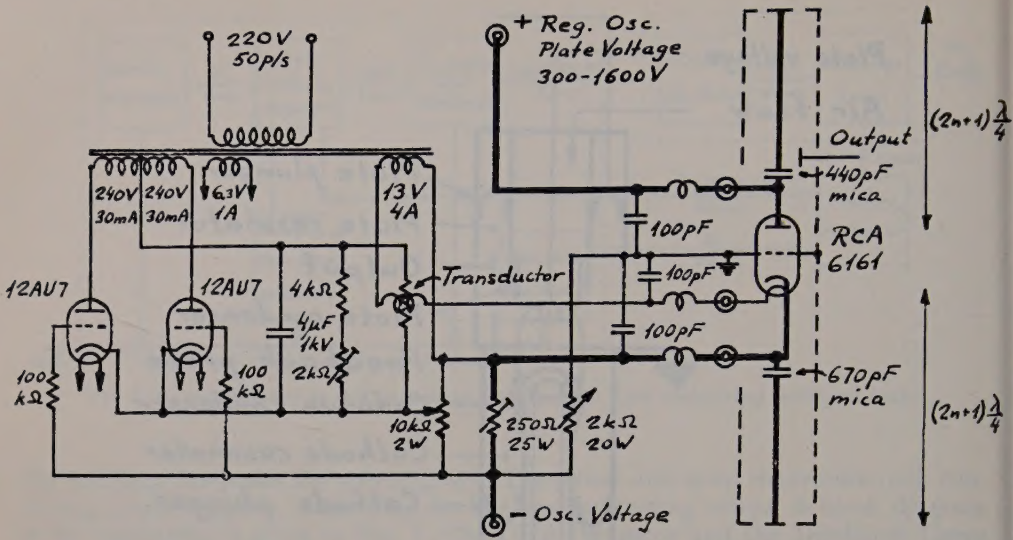

Fig. 3. DC circuit and heater supply for the UHF oscillator tube RCA 6161.

back is variable by means of turning three symmetrically placed probes giving capacitive coupling. The coupling degree is critical at the highest frequencies covered, but the variation range is enough without using inductive couplers. Some of the details concerning the mechanical construction of the oscillator unit are shown in Fig. 4.

The high frequency output is capacitive and taken through a 10 mm slit in the outer conductor of the plate resonator. It will be described in connection with the load circuits and discharge lamps.

The light intensity stabilizer

The input voltage to the oscillator triode and therefore also, in most cases, the light intensity of the discharge lamp can be regulated automatically, or by hand. The automatic regulation implies stabilization of the light intensity, which is made in order to make possible the scanning of spectra by photoelectric devices giving the line intensities. The fluctuations in light intensity are in this case less than can be directly detected by a photomultiplier, with the equipment working at common conditions over several hours. The regulation by hand gives adjustable stabilized input plate voltage to the oscillator triode.

The automatic regulation is attained by a feedback loop shown principally in the block diagram Fig. 1 and in some detail in Fig. 5, where the Automatic–By Hand switch is drawn in the position Automatic. A very narrow beam of light from the Discharge Lamp is let through a collimator with an iris diaphragm to the cathode of the Photomultiplier, 1P21 or any type suitable for the wavelength in question. The multiplier can also be inserted into the spectrograph and adjusted to collect any chosen wavelength. The photocurrent gives a voltage drop across a high stability 40 MΩ resistor, connected to the input of a differential amplifier in the Light Intensity Regulator. The amplifier output is connected to four RCA 807, acting as series regulator

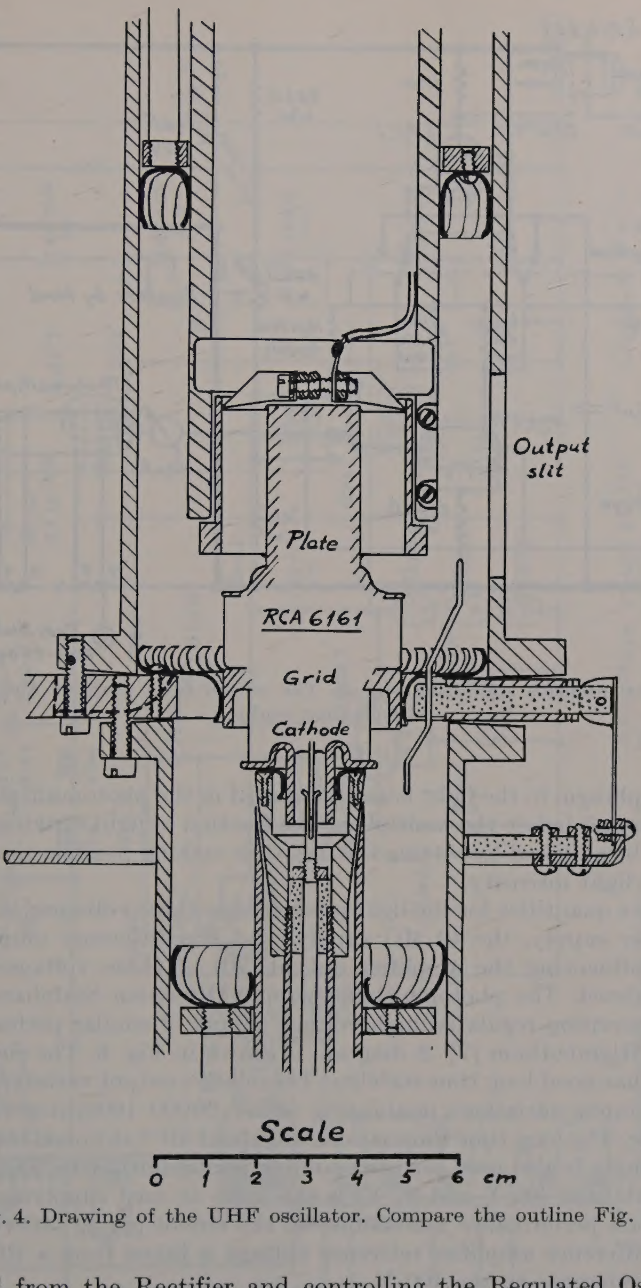

Fig. 4. Drawing of the UHF oscillator. Compare the outline Fig. 2.

tubes supplied from the Rectifier and controlling the Regulated Oscillator Plate Voltage, which is connected to the plate of the oscillator triode through the overload relay in the Protection and Heater Supply sub-unit. The direction of regulation is such that a tendency of increase in photo current gives a decrease in oscillator plate voltage, thus giving the desired stabilization.

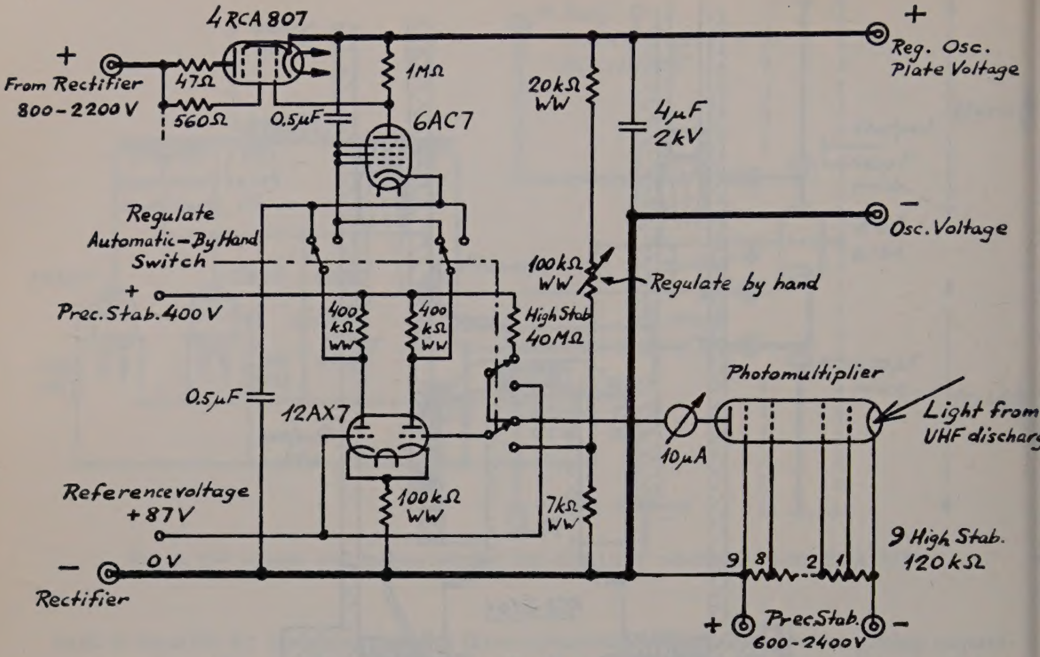

Fig. 5. The light intensity stabilizing circuit. The switch is in position Automatic, i.e. light stabilization working.

The iris diaphragm in the light beam is situated in the photomultiplier unit behind a light diffuser and before the multiplier. The fraction of light striking the multiplier can therefore be adjusted by setting the iris, thus making possible the adjustment of the stabilized light intensity.

The reference quantities for the light intensity are three voltages, because both the photomultiplier supply, the 40 MΩ supply, and the difference amplifier reference voltage are influencing the amplifier output. All of these voltages are therefore precision regulated. The photomultiplier supply (Precision Stabilized 600–2000 V) consists of a precision regulated high voltage supply of similar performance to that described by Higinbotham [7]. A diagram is shown in Fig. 6. The supply works excellently and has good long time stability. The relative output variations are 5×10^{-6}–10^{-4} at 10% input variations (stabilizing factor 20000–1000) depending upon the output voltage. The long time fluctuations are about 10^{-4} at normal operating conditions. This supply is also used for the scanning photomultipliers. The 40 MΩ supply (Precision Stabilized 400 V and 87 V) is the same as used supplying the amplifier. It is of common performance and similar to the circuit giving 500 V in the supply, Fig. 6. The difference amplifier reference voltage is taken from a RCA 5651 and is also used for reference to the 400 V.

Some qualities of the light intensity stabilization are worth mentioning in addition to the description above. The UHF discharge appears in some cases to have a rather complicated light output versus oscillator power input characteristic. The slope of this characteristic is ordinarily positive, but can also be zero, or even negative, in

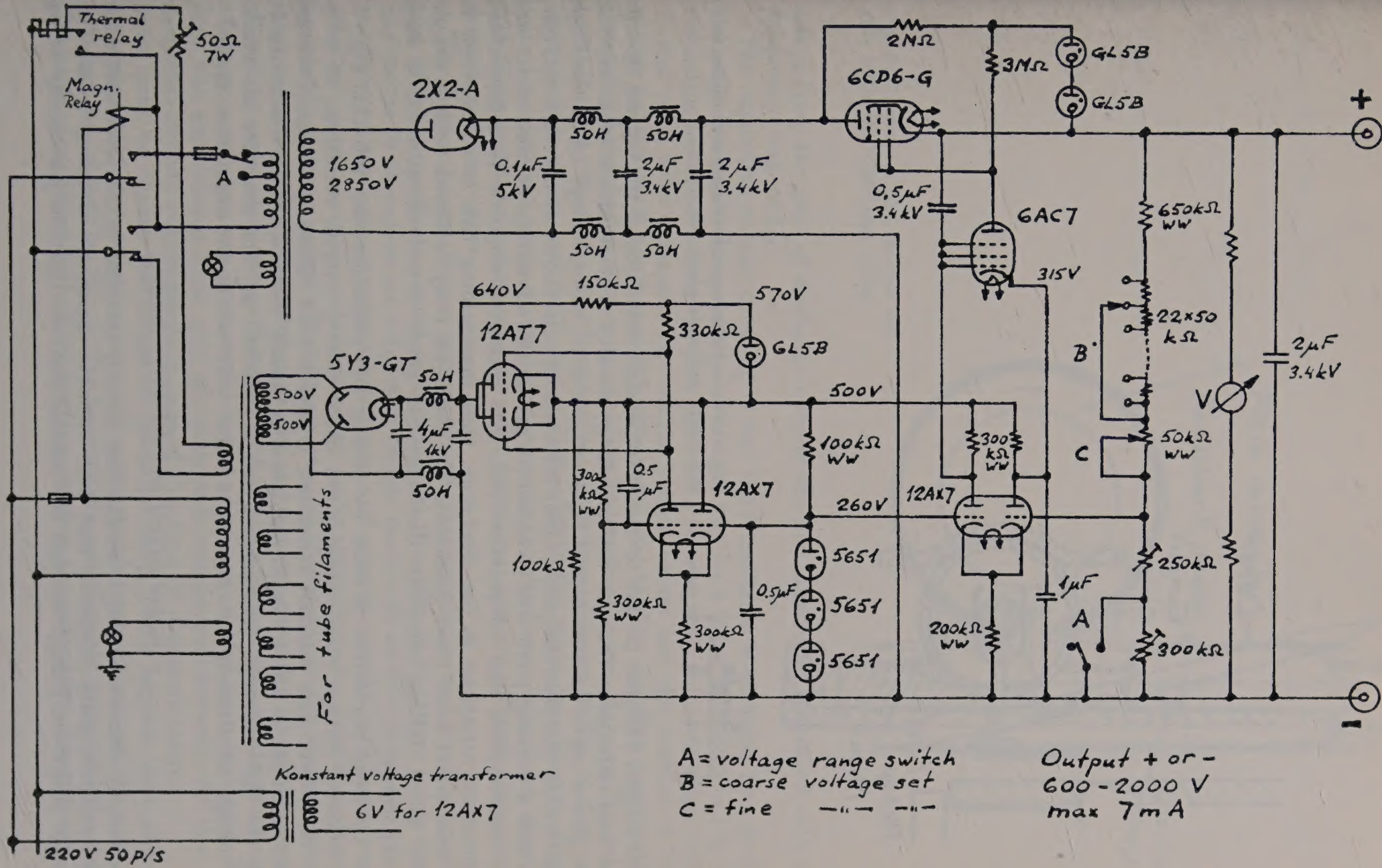

Fig. 6. Precision stabilized voltage supply 600–2000 V.

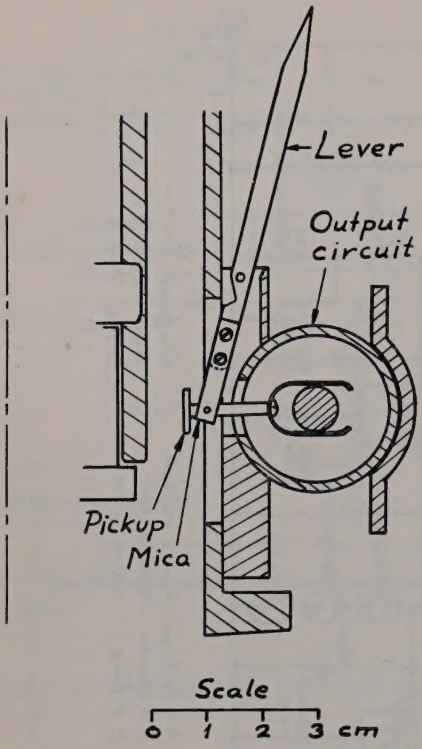

Fig. 7. The variable capacitive output coupling from the UHF oscillator plate resonator.

certain ranges. This can be due to loss of impedance matching of the output circuit, as the load impedance changes with discharge density. The stabilizer seeks out the lowest power input for the desired light output in all cases, except when the slope is negative. In this case the power input is increased until the overload relay cuts out. Otherwise a working point will be obtained, giving the advantage of minimum total power consumption and temperature rise. The stabilizer responds to temperature and pressure variations in the discharge, thus maintaining this in cases when it otherwise would have been quenched. The overload relay is fitted with a simple audible alarm, telling when the discharge has gone—a convenient detail at long time exposures.

The by hand regulation is done by setting the potentiometer 100 kΩ, Fig. 5. The obtained voltage stabilization gives about 0.03 % output variations at 10 % input variations. The internal resistance is about 10Ω. These qualities, however, are not essential, as the by hand regulation is mainly used to obtain conditions at which the light intensity stabilization can be switched on. The Rectifier has coarse step voltage adjustment for choosing a value well within the regulation range.

Output circuit and discharge lamps

The output circuit is a tunable coaxial line, directly attached to the outer conductor of the oscillator plate resonator and with variable capacitive coupling to it. The discharge lamps are placed through the coaxial line, the light output mostly being

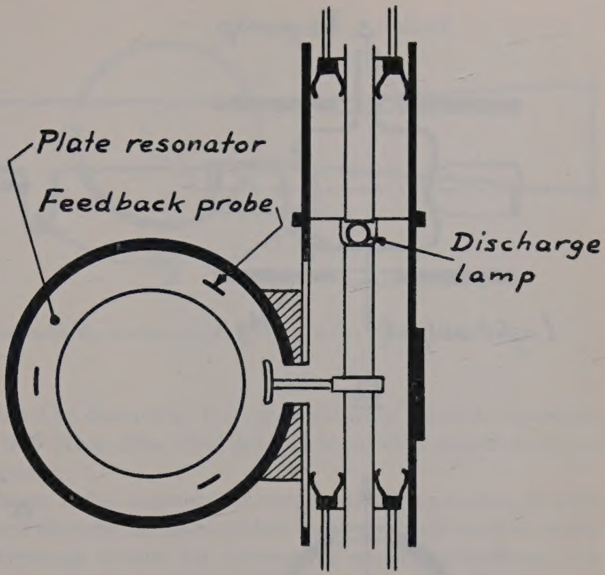

Fig. 8. Outline of the output circuit with the discharge lamp.

taken from the part of discharge outside the line. Discharge is started with a high frequency leak tester.

The capacitive output coupling of the UHF oscillator is obtained by a pick-up in the plate resonator. It is varied in a simple way by a lever, as shown in Fig. 7. The insulating material holding the pick-up rod is a very exposed point and other materials except mica were damaged. The coaxial output circuit and the position of the discharge lamp is similar to that used by Forrester *et al.* [4]. The coupling point on the line can easily be moved in relation to the lamp by pushing the line, the coupling rod being let through a slit in the outer conductor. An outline is shown in Fig. 8. Two output circuits were made, one 71 Ω, and the other 33 Ω, the latter long enough to permit use of a standing wave meter for measuring the discharge lamp load impedance. The inner and outer conductors are made from brass and the shortcircuiting plungers from beryllium-copper.

The discharge lamp was to give small spectral line widths, and for that purpose all line broadening effects should be avoided. In the type of discharge tubes used the gas atoms or molecules are subject to termal motion in all directions and therefore the light emitting gas or vapor temperature and pressure should be as low as possible. Further, inert or other extraneous gas for maintaining the discharge should be avoided in order to escape red shift, reported by Barrell [8], and pressure broadening. Also inserting the light emitting gas in the form of part of a chemical compound should be avoided to escape formation of extraneous elements by dissociation. But all these conditions are detrimental to the obtaining of high light intensity. Therefore, the experiments must give an acceptable compromise between the line width and light density requirements in case of this type of discharge lamp.

In order to choose the design of discharge lamp giving highest light density in an area suitable for projecting on a slit, many designs were examined, the main types of which are shown in Fig. 9. The lamps were continuously pumped by a mercury diffusion pump fitted with a dry ice trap, holding the extraneous gas pressure below

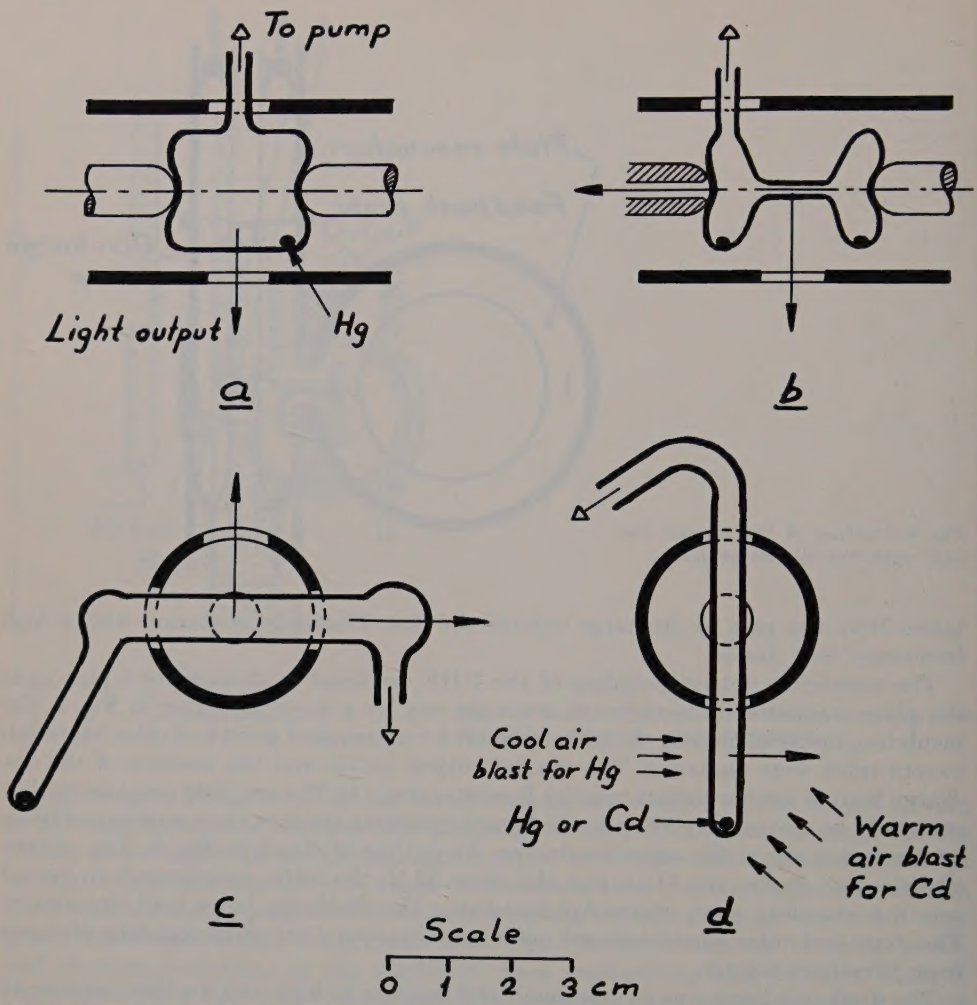

Fig. 9. Main types of discharge lamps examined in different sizes. The simplest and best type is *d*.

0.0001 mm Hg. For these examinations mercury vapor was chosen as the emitting gas for the easiness of controlling the pressure by the temperature of the mercury surface. It was found suitable to hold the mercury at approximately room temperature, corresponding to about 0.001 mm Hg just above the surface. The pressure in the discharge itself must be slightly lower. The mercury temperature was held by cooling the tube by a cold air blast. The vapor temperature in the discharge, however, differs from the surface temperature by energy transfer from the excited electrons in the UHF field, and is hard to determine. The discharge part of the lamp tube was cooled as well as possible.

The light density is greatly influenced by the diameter of the discharge tube, decreasing diameter giving increasing density. As the maintenance of the discharge

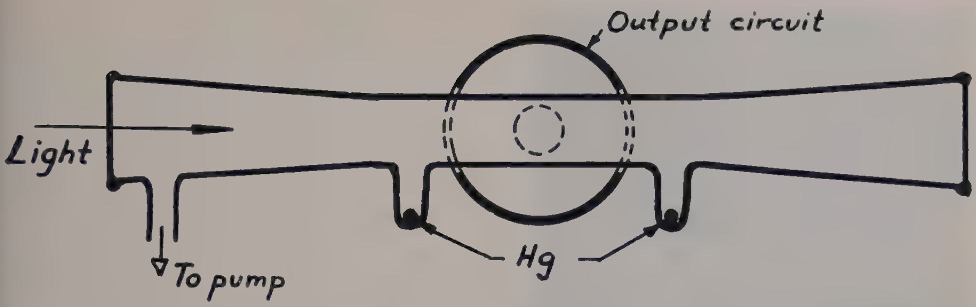

Fig. 10. Absorption cell for metastable states excited by a weak UHF discharge.

becomes more difficult the smaller the diameter, the most suitable internal diameter is about 3 mm for mercury at 1000 Mc/s. The discharge is then very stable and can burn for tens of hours continuously.

The discharge in the thin discharge tubes extends far outside the coaxial line, mostly showing a weak minimum between the end surfaces of the inner conductors due to the radial UHF field. Often the discharge shows up moving or resting striations, the interval length of which has no correlation with the UHF wavelength. The part of the discharge closely outside the line was found to be the best for our purpose, and the discharge outside that point was quenched, or diminished, by a few small metal strips wrapped around the discharge tube at suitable positions. Thus, the type of lamp design recommended is the simplest one, Fig. 9*d*. The discharge tube material is Pyrex or fused quartz. The Pyrex types are sometimes damaged by dielectrical overheating at a point touching an inner conductor.

The lamp design chosen has been used with Hg and Cd. The Hg-lamp with 3 mm internal diameter was operated with a vapor pressure about 1.5×10^{-3} mm Hg and a discharge tube wall temperature of about 20°C. The Cd-lamp discharge is more stable with 4 mm internal diameter. It was operated with a Cd surface temperature of 215°C, corresponding to a vapor pressure of about 0.8×10^{-3} mm Hg, and a discharge wall temperature some ten degrees lower. The temperature was held by a warm air blast.

For purpose of absorption measurements on metastable states, some discharge absorption tubes of different lengths have been made according to Fig. 10. The diameter is about 10 mm, and the discharge maximum length in this tube is about 50 cm at 1000 Mc/s with Hg vapor pressure of about 1.2×10^{-3} mm Hg.

The load impedance of the discharge lamp was measured by using the 33 Ω output line circuit and a standing wave meter specially made for this purpose. The meter is of common design with a 1N23 detector and a variable quarter wavelength stub. The impedance measured for a lamp as Fig. 9*d* at high light output was 61 Ω.

Line widths

For the line width examination of the obtained light *Hulthén immersion grating spectrographs* [9, 10] were exploited, the resolving power of the best instrument being over 10^6 for 5000 Å wavelength. The line widths are best shown by reproductions of some recordings. UHF oscillator frequency is 1000 Mc/s.

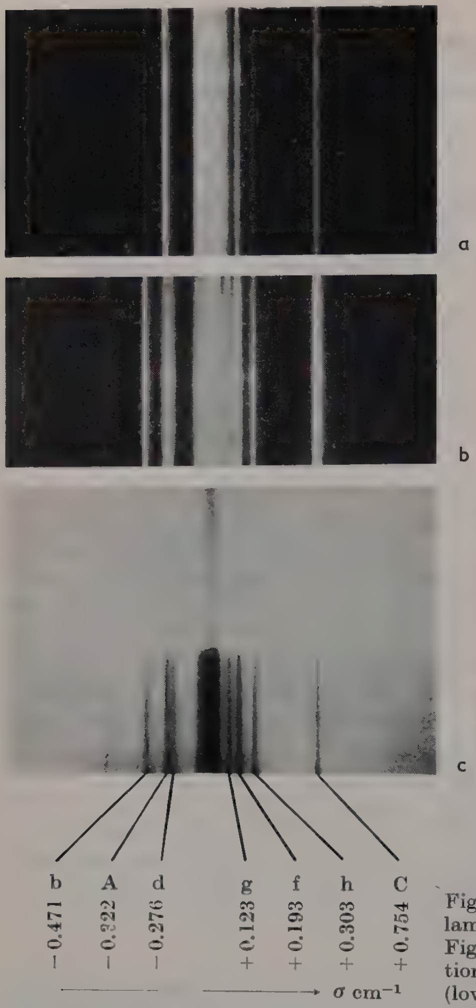

Fig. 11. Hg 5461 Å, single diffraction. (*a*) Emission, lamp Fig. 9*d*. (*b*) Emission from deep layer, lamp Fig. 9*c*, formation of false structure by self-absorption. (*c*) Absorption in 6 cm (upper part) and 45 cm (lower part) length of discharge in tube Fig. 10.

The recordings in Fig. 11 are taken with an échelle grating with 80 grooves per mm and aperture 3 cm times 7 cm using alphabromnaphthalene as immersion fluid and a 30/60° prism with one convex surface giving a focal length of 4.5 m. Single diffraction is used and the order is about 70. Fig. 11*a* shows the line Hg 5461 Å in emission. Lamp type Fig. 9*d* with weak discharge and exposure time 20 min. Fig. 11*b* shows the same line from a lamp Fig. 9*c*, the light taken out as shown by the arrow directed to the right. Here the deep emission layer gives broadening of the lines and changing the intensity relations between them due to self absorption. A false structure in the center line is also formed. Exposure time 7 min. Fig. 11*c* shows 5461 in absorption, the length of discharge in the tube Fig. 10 being about 6 cm for the upper part and 45 cm for the lower. Exposure time 15 min.

The recording in Fig. 12 shows the central line even isotope components of Hg

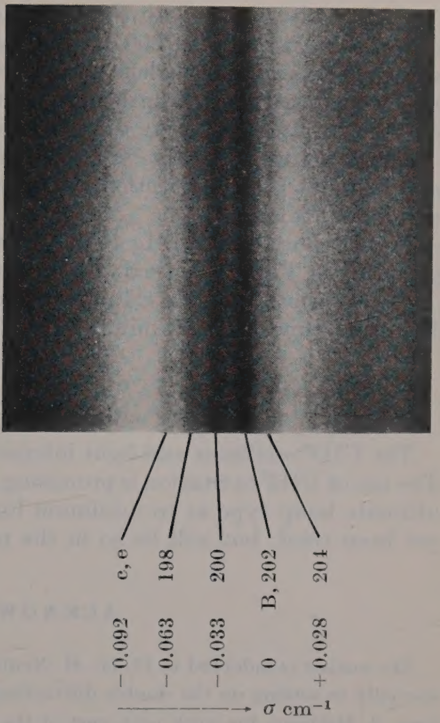

Fig. 12. Hg 5461 Å, central line even isotope components, double diffraction with linear dispersion 15.0 mm/Å. Absorption in 5 cm discharge tube Fig. 10.

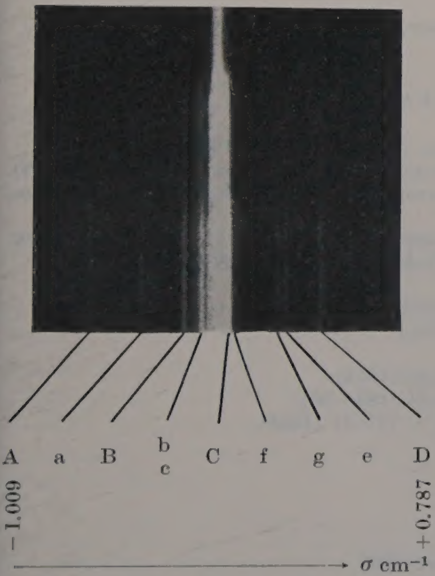

Fig. 13. Hg 4358 Å, single diffraction, emission, lamp Fig. 9*d*.

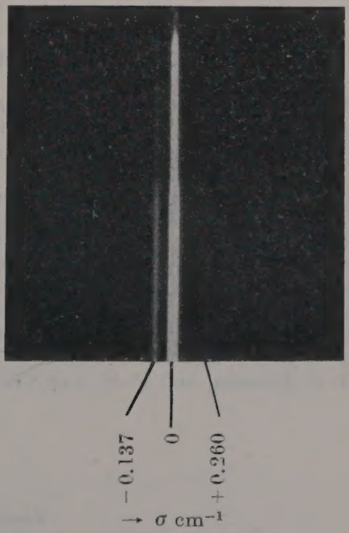

Fig. 14. Cd 4678 Å, single diffraction, emission, lamp Fig. 9*d*.

5461 Å in absorption with the length of absorbing discharge 5 cm. It is taken with an échelle grating with 300 grooves per mm and aperture 4 cm times 8 cm, again using alphabromnaphthalene as immersion fluid. A 30/60° prism with plane surfaces and a lens with focal length 6 m are used. The spectrograph is arranged in double diffraction giving a linear dispersion of 15.0 mm/Å. Exposure time 1.5 h.

The structure of the Hg 5461 Å line is in accordance with the calculations of Schüler and Schmidt [11]. Absorption measurements have previously been made by Burger and van Cittert [12].

Fig. 13 shows the line Hg 4358 Å in emission from lamp Fig. 9*d*. The same spectrograph as in Fig. 11 is used. Exposure time 1, 4, and 8 min.

Fig. 14 shows the line Cd 4678 Å from lamp Fig. 9*d*. Spectrograph as in Fig. 11. Exposure time 3 and 6 min.

Conclusions

The UHF oscillator and light intensity stabilizer described here work satisfactorily. The use of UHF excitation is promising for high light output and small line width. The ultimate lamp type as to minimum line broadening, the atomic beam lamp, has not yet been tried, but will be so in the near future.

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